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ON LIGHT REFRACTION IN THE ATMOSPHERE OF VENUS

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SUMMARY

Calculation of light refraction is conducted on the basis of data on direct investigations of Venus' atmosphere with the aid of Soviet AS "VENERA-4".

It is established that at an altitude of 8.3 km from the assumed surface, horizontal rays by-pass the planet over a circumference. Trajectories of light rays, originating from the assumed surface of the planet at various angles, are computed. It is shown that the rays returning to the surface are those emitted at angles to horizon not exceeding 2°.

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As a result of the successful flight of AS "VENERA-4" fundamental physico-chemical data have been obtained on the lower atmosphere of planet Venus. The information on the composition and density of Venus' atmosphere allows us to conduct calculations of light refraction so as to obtain a representation on optical phenomena taking place near its surface. As a result, profiles were obtained of the index of refraction and its gradient in the atmosphere of Venus. The position was defined of the critical sphere containing the rays of light propagating around the planet along closed circumferences and the calculation has been conducted of light ray trajectories, propagating in the vicinity of planet's surface.

(*) O REFRAKTSII SVETA V ATMOSFERE VENERY

INDEX OF REFRACTION IN VENUS' ATMOSPHERE AND ITS GRADIENT. Profiles of density and of its gradient in the atmosphere of Venus about 25 km thick, traversed by AIS "VENERA-4", borrowed from [1], are represented in Figure 1.

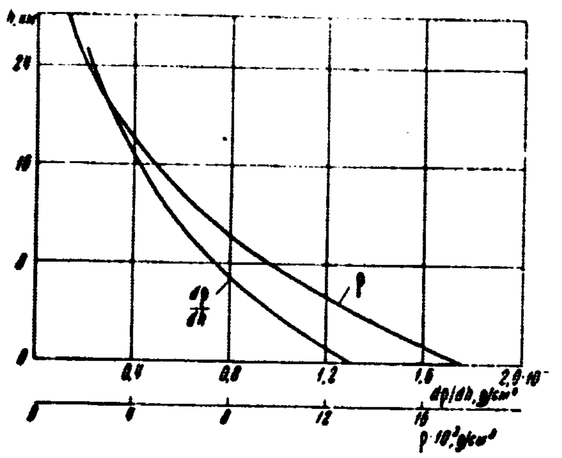

Fig.1

Calculations of the index of refraction and of its gradient were conducted with the use of Fig.1 data according to the well known formula

$$\frac{n-1}{\rho} = k. \qquad (1)$$

Here n is the index of refraction, ρ is the density and k is the Gladstone-Dale constant determined by the composition of the atmosphere. According to data obtained from VENERA-4, the atmosphere of the planet contains about 90% CO_2; this is why all calculations were conducted for an atmosphere consisting entirely of carbon dioxide. According to literature data the value of k for CO_2 varies within the limits 0.227 — 0.22 cm^3/g [2 — 4].

The obtained dependence of the refraction index of Venus' atmosphere on the altitude h for both values of k is plotted in Figure 2 (next page). The divergence between the two curves is less than three percent (3%). Shown in the same figure is the course of the gradient of the refraction index ($k = 0.227$ cm^3/g). This graph is fundamental for the subsequent calculations of refraction. The results, borrowed from the work [5], are also shown in Fig.2 by a dashed line. One may notice that the results of measurements in the upper part of the atmosphere [5] "butt in" with the data obtained here. The tying of coordinates was done in correspondence with [1]. It is also interesting to note that the points, obtained during direct determination of (n — 1) (dashed line) in Fig.2 with the curve for $k = 0.227$, passes in the lower layers of the atmosphere gradually to the curve for $k = 0.22$; it is possible that this is linked with the dependence of CO_2 refraction on temperature [4].

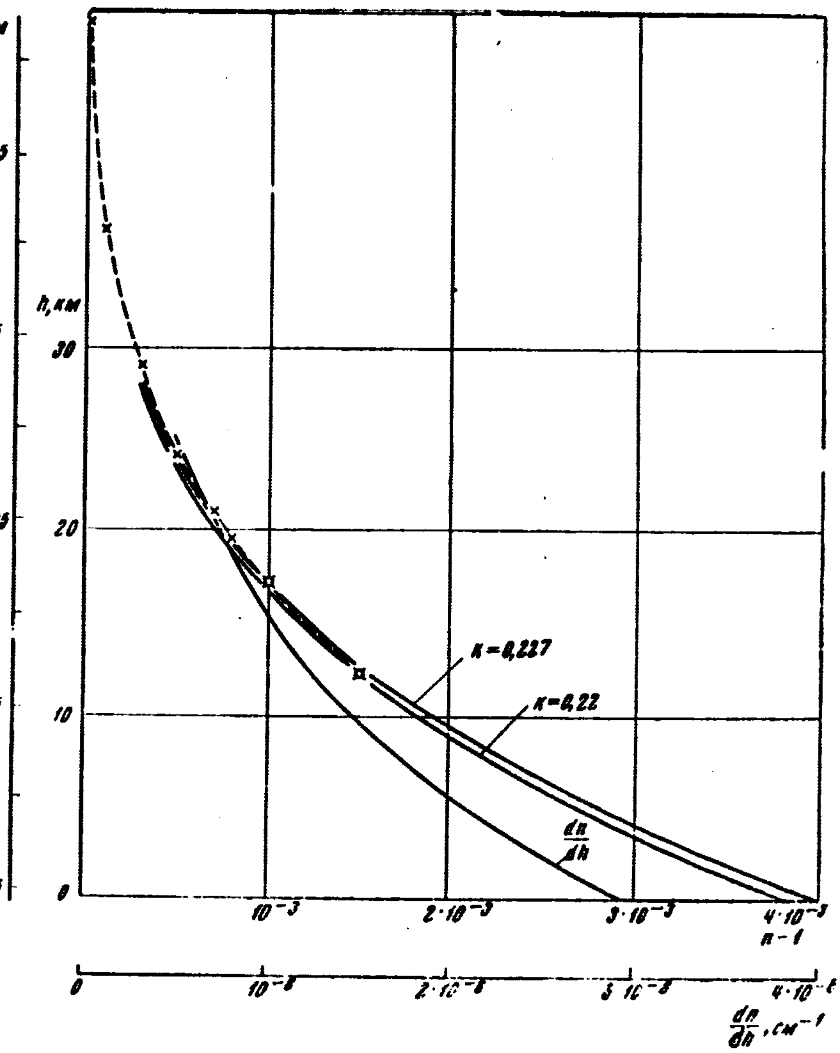

Fig.2

PROPAGATION OF LIGHT AROUND THE PLANET

It is well known that the curvature radius of a light ray propagating in an isotropic medium is inversely proportional to the gradient of the index of refraction. On the basis of this, for a ray of light, propagating around the planet along a concentric circumference, one may write the following equation:

$$\left(\frac{\partial n}{\partial r}\right)^{*} = \frac{1}{R^{*}} = \frac{1}{R_0 + h^{*}}. \qquad (2)$$

Here R^* is the radius of the critical sphere; R_0 is the radius of the planet, h is the height of the critical sphere above the planet surface and $(\partial n / \partial r)^*$ is the critical value of the refractive index' gradient.

In the first approximation we shall take for the quantity R^* the radius R_0^*, responding to the point h = 0 in Fig.1; in [1] this level was assumed for the position of planet's surface. Assuming in accord with [6] and Fig.2, $R_0^* = 6076$ km, we shall obtain

$$\left(\frac{\partial n}{\partial r}\right)_0^* = \left(\frac{\partial n}{\partial h}\right)^* = 0{,}164\cdot 10^{-8} cm^{-1}.$$

The corresponding value of density gradient is $0.723\cdot 10^{-8}$ g/cm^4. In Fig.1 and 2 to these values of gradients responds the height $h^* = 8.3$ km. Consequently, the critical surface is located at an altitude of ~ 8.3 km from a surface responding to $R_0^* = 6076$ km, up to which data on Venus' atmosphere are available. Inasmuch as $h^* \ll R_0^*$, further refinements of $(\partial n / \partial r)^*$/and h^* should yield no substantial correction in correspondence with formula (2); it constitutes in all ~ 0.14%. Taking into account that all initial values are well known with noticeably great errors, the obtained correction may not be introduced into the value of $(\partial n / \partial r)^*$ sought for. At k = 0.22, $h^* \approx 8.0$ km. With an error of no more than 0.5%, to the found value of the critical gradient could satisfy a region of the atmosphere in the neihborhood of $R_0^* = 6076$ km, 30 km thick. If in accord with [7], we should assume for the radius of the planet $R_0 = 6056$ km, the altitude of the critical surface from the planet surface would constitute $h_0^* = 28.3$ km. Subsequert refinements of data on Venus' atmosphere will allow us to introduce into the values and results obtained here the corresponding corrections; they will also apparently provide the possibility of penetrating into deeper layers of the planetary atmosphere. However, one may hope that the position of the critical sphere in the field of the gradient of the refractive index and the position relative to this surface of the light ray paths obtained below near it, will not change substantially.

PROPAGATION OF LIGHT RAYS NEAR THE SURFACE OF THE PLANET

Taking into account the linear character of the dependence of the light ray deflection angle on the value of the gradient of the index of refraction, the aggregate deflection ε_Σ may be broken into two parts: $\varepsilon_\Sigma = \phi + \varepsilon$. One of the parts, $\phi = \varepsilon^*$ is conditioned by the constant component of the gradient $(\partial n / \partial h)^*$, appearing to be the cause of ray motion around the planet along the surface. The variable part of ε, inducing the displacement of the ray relative to the planet's surface, is due to the influence of the residual part of the index of refraction gradient $\partial n / \partial h$. Then, considering only the motion of the ray relative to planet's surface and approximating at the same time the variable part of $\partial n / \partial h$ over separate portions of the graph of Fig.2 in the form of a straight line $\partial n / \partial h = a - \alpha h$, we may obtain the differential equation of motion of the ray in the following form:

$$n \frac{d^2 h}{ds^2} = a - \alpha h. \tag{3}$$

Here a and α are constants, determined by the Fig.2. Eq.(3) is written in a curvilinear system of coordinates (sOh), in which the axis Os is directed parallelwise to planet's surface at the level $R^* = 6076$ km ($h = 0$), and the axis Oh coincides everywhere with the direction of the radius. Resolving (3) at boundary conditions $s = 0$, $h = h_0$, $dh / ds = \delta_0$ for the trajectories of rays proceeding near the planet's surface, we shall obtain

$$s_{1/2} = \frac{1}{\sqrt{\alpha}} \operatorname{ArCh} \frac{a - \alpha h}{a - \alpha h_0}. \tag{4}$$

The trajectory of rays initially proceeding parallelwise to the surface of the planet is obtained from (4) at $\delta_0 = 0$

$$h = \frac{a}{\alpha} + \left(h_0 - \frac{a}{\alpha} - \frac{\delta_0}{\sqrt{\alpha}} \right) \operatorname{Ch}(\sqrt{\alpha} s) + \frac{\delta_0}{\sqrt{\alpha}} e^{\sqrt{\alpha} s}. \tag{5}$$

Here h_0 is the maximum value of h; in (5) $h = h_0$ at $s_{1/2} = 0$. The index $1/2$ signifies that this equation describes only one half of the trajectory determined by Eq.(4). The second half of the trajectory is symmetrical to it on the strength of light ray reversibility. For the inclination angle of the ray of light to planet's surface, from (5) we may obtain the following expression:

$$\varepsilon = \frac{dh}{ds} = \frac{1}{\sqrt{\alpha}} (\alpha h_0 - a) \operatorname{Sh}(\sqrt{\alpha} s_{1/2}). \tag{6}$$

When computing the trajectories of rays lying below the critical altitude $h^* = 8.3$ km, the values of parameters were as follows: $a = 0.119 \cdot 10^{-8}$ cm^{-1}, $\alpha = 0.144 \cdot 10^{-4}$ cm^{-2}.

In the curvilinear system of coordinates the rays, proceeding at the altitude of 8.3 km, are not deflected, which is visible from relations (5) and (6); at $\alpha h_0 = a$, the latter vanishes ($\varepsilon_{8.3} \equiv 0$), while the first becomes infinite. At $h_0 = h^*$, function (5) undergoes a discontinuity; the light ray then propagates parallelwise to the surface of the planet.

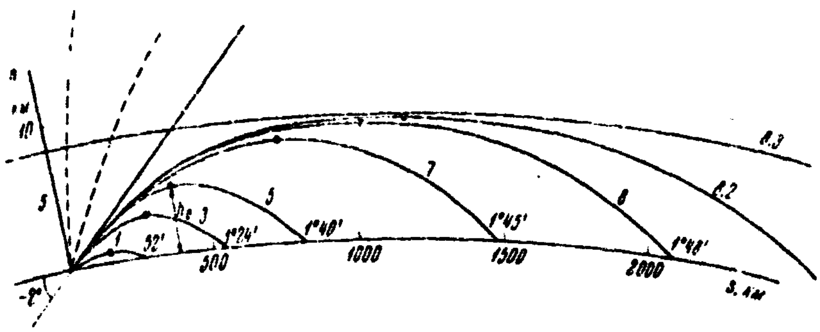

Fig.3(*)

The incidence angles of light rays on the planet's surface were computed by formula (6) (ε_0). The results of calculation as a function of h_0 are plotted in Fig.4. It is fairly easy to see that as h_0 increases (and consequently $s_{1\,2max}$ also), the angles of incidence of rays do not rise unboundedly. For $h_0 > 7$ km, the angle ε_0 already varies unnoticeably and approaches the limit $\varepsilon_{0max} = -a/\sqrt{\alpha}$, which constitutes for the assumed values of α and $\underline{a}$ the value of 0.0321, or in degrees: 1°50'. Therefore, the angle $\varepsilon_{0max} = \delta_{0max} = 1°50'$ is a threshold for the rays returning to the planet. The rays outgoing at angles greater than 1°50' do not return to the planet. The trajectories of rays outgoing from the planet at different angles δ_0 and, at the same time rising to a different altitude, are plotted in Figure 3 above. Here dots denote the centers of trajectories, where the rays become parallel to the surface of the planet. As may be see from Fig.3, distances s_{max} increase rapidly with the rise of δ_0 and h_0, this rise being particularly noticeable at rapprochement to $h^* = 8.3$ km, where distontinuity of function (5) takes place. But this phenomenon is observed only in a very narrow region directly adjacent to $h^* = 8.3$ km, which is clearly seen from

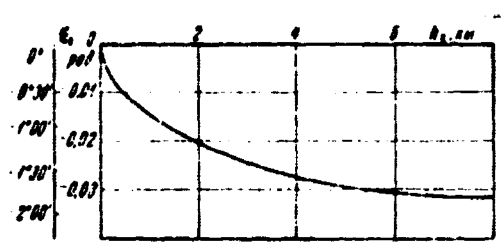

Fig.4
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(*) [for practical purposes Figs.3 and 4 of the original version have been interverted].

the data compiled in Table 1 below. Here Δh_0 is the distance of the rays from the "critical" surface, assuming $h^* = 8.3$ km.

TABLE 1

Δh_0, м	70	7	$7 \cdot 10^{-4}$	$7 \cdot 10^{-6}$
s_{max}, км	2880	5260	10140	12600

It may be seen from Table 1 that greater distances are covered by rays proceeding in a very narrow region of space. The distances exceeding 12,000 km are covered by rays passing in a channel with width of the order of 0.007 mm. Consequently, part of the light from the sunlit side of the planet may also penetrate in its night part to fairly great distances. But only a small amount of energy will then be transferred in that very narrow light channel. To an observer located on an even or smooth surface, a faraway horizon will appear, outgoing to numerous thousand kilometers with an insignificant rise of the locality, constituting less than 2°.

CONCLUSION. We should note that all the conclusions and calculations conducted here are valid only for a quiet atmosphere with spherical symmetry. The analysis of refraction conducted here is based upon the results of the first direct investigation of Venus' atmosphere parameters. The refinement of the obtained results may be conducted alongside with su sequent study of planet's parameters and its geometric characteristics.

*** THE END ***

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REFERENCES

1. V. S. AVDUYEVSKIY, N. F. BORODIN, V.A. KUZNETSOF... ET AL. DAN, 199, 2, 1968.
2. HANDBOOK OF CHEMISTRY AND PHYSICS. Ed.37, USA.
3. M. P. VULAKOVICH, V. V. ALTUNIN. Teplofizicheskiye svouystva dvuokisi ugleroda (Thermophysical properties of CO_2). Atomizdat, 1965.
4. A. MUCHELS, J. HAMERS. Physica, 4, 995, 1937.
5. MARINER STANFORD GROUP SCIENCE, 158, 1678, 19 7.
6. V. S. AVDUYEVSKIY, M. YA. MAROV, M. K. ROZHDESTVENSKIY. Kosm. Issledov. 7, No.2, 233, 1969.
7. M. E. ASH, I. I. SHAPIRO, W. B. SMITH. Astronom. J. 72, 338, 1967.

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